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Surface energy balance measurements in wind energy experiments

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MOTIVATION

It may seem like a paradox, but with the growing height of the wind turbines, the influence of the surface fluxes become more important for understanding the wind and turbulence profile over a rotor plane. This is because the surface energy balance is directly connected to both the height of the atmospheric boundary layer and the thermal stratification, which in combination are key parameters controlling the turbulence and wind profiles in the relevant height range for future turbines.

Old micro-scale models neglected these effects and were limited to the near-neutral stratification, but current mesoscale and future micro-scale models need to include a surface energy balance for maximum benefit for the wind energy applications. The planned EERA experiments should be instrumented to meet the needs of the next-generation modellers. We therefore propose a mast set-up that includes the most important components of the surface energy balance.

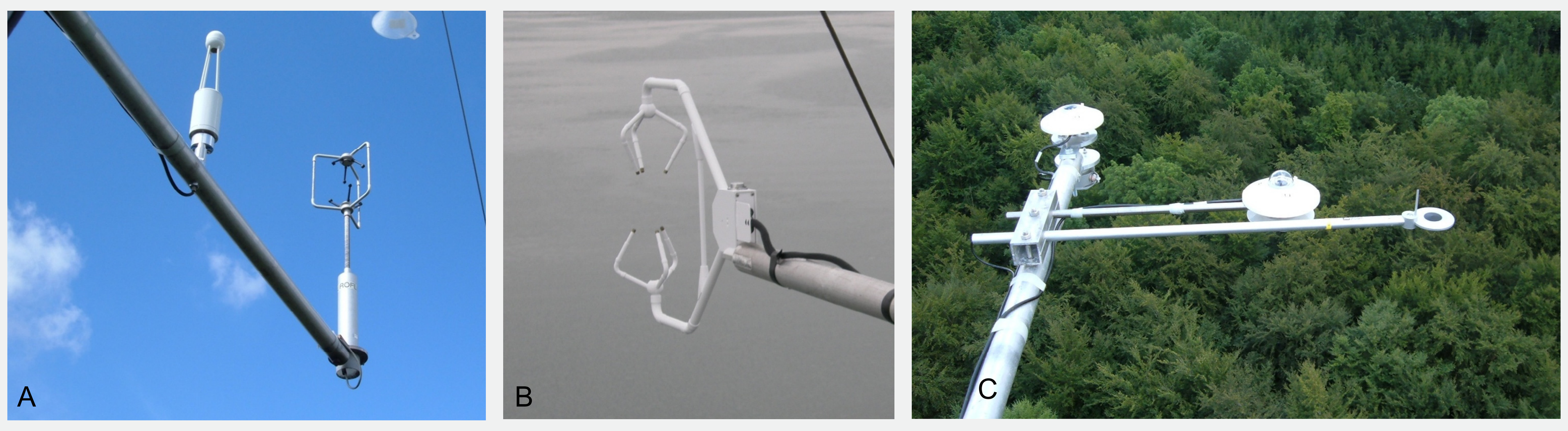


Figure 1: Instruments associated with surface energy balance measurements.

THE SURFACE ENERGY BALANCE - AND HOW TO MEASURE IT

The surface energy balance can be expressed as

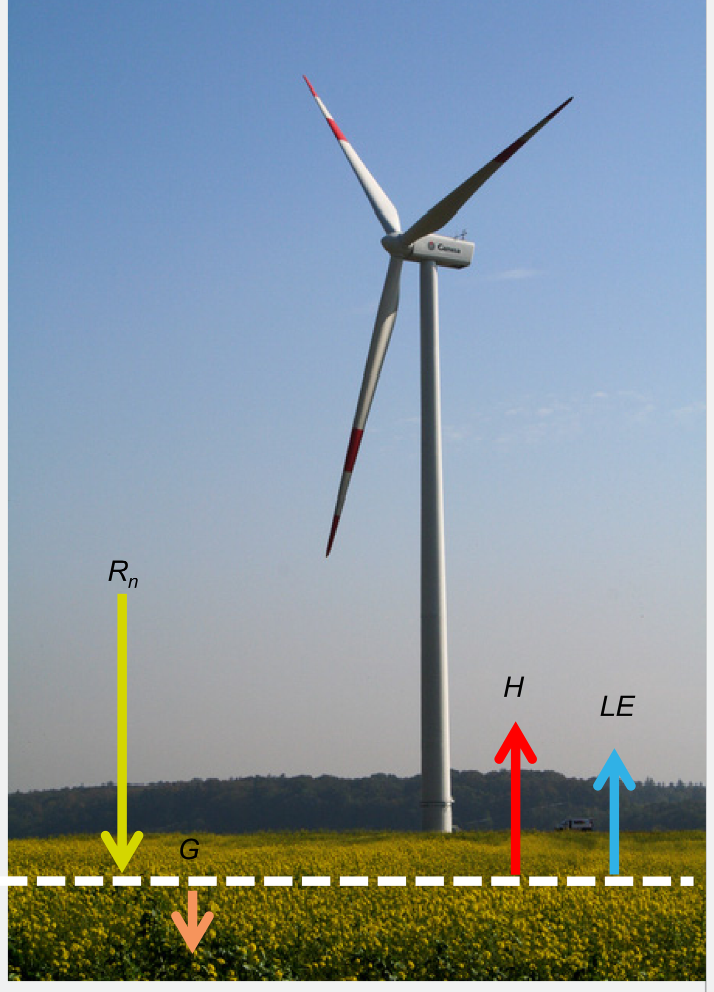
$$R_n - G = H + \lambda E \qquad (1)$$

where R_n is the net radiation, G the heat flux into the soil and H and λE are the sensible and latent heat transfer respectively. The net radiation can be split up into the following components

$$R_n = S\downarrow - S\uparrow + L\downarrow - L\uparrow \qquad (2)$$

where S represents the shortwave solar (or global) radiation, L is the long-wave radiation and the arrows denote the direction of the radiation components.

Figure 2: The components of the surface energy balance.



The radiation balance can be easily assessed by either a net radiometer or instruments that measure the four components in (2). An example setup from the Sorø forest, Denmark, is given in Figure 1c. Whereas advection of heat is more difficult to assess from a single mast, the measurement of the vertical turbulent heat transfer is straight-forward. A sonic anemometer can measure the sensible heat flux, and the combination of a sonic anemometer and a fast responding sensor for water vapor (Figure 1a) enables the calculation of the turbulent parts of H and λE in (1). Finally, the soil heat flux can be measured by plates inserted into the soil.

MAST SETUP

In Figure 4 below, a suggestion for a wind energy mast configuration with surface energy balance measurements is given. The latent heat flux measurements should be measured at at least two heights, in order to be able to study flux divergence over changing footprint areas. Three -dimensional sonic anemometers and thermometers are suggested at all measurement levels. A net radiometer is placed near the bottom of the mast, whereas the four component radiometer is placed at the top of the mast in order to maximize the area seen by the downward facing sensors and minimize the shading of the mast on the upward facing sensors.

Naturally, the setup should be adapted to the site of measurement.

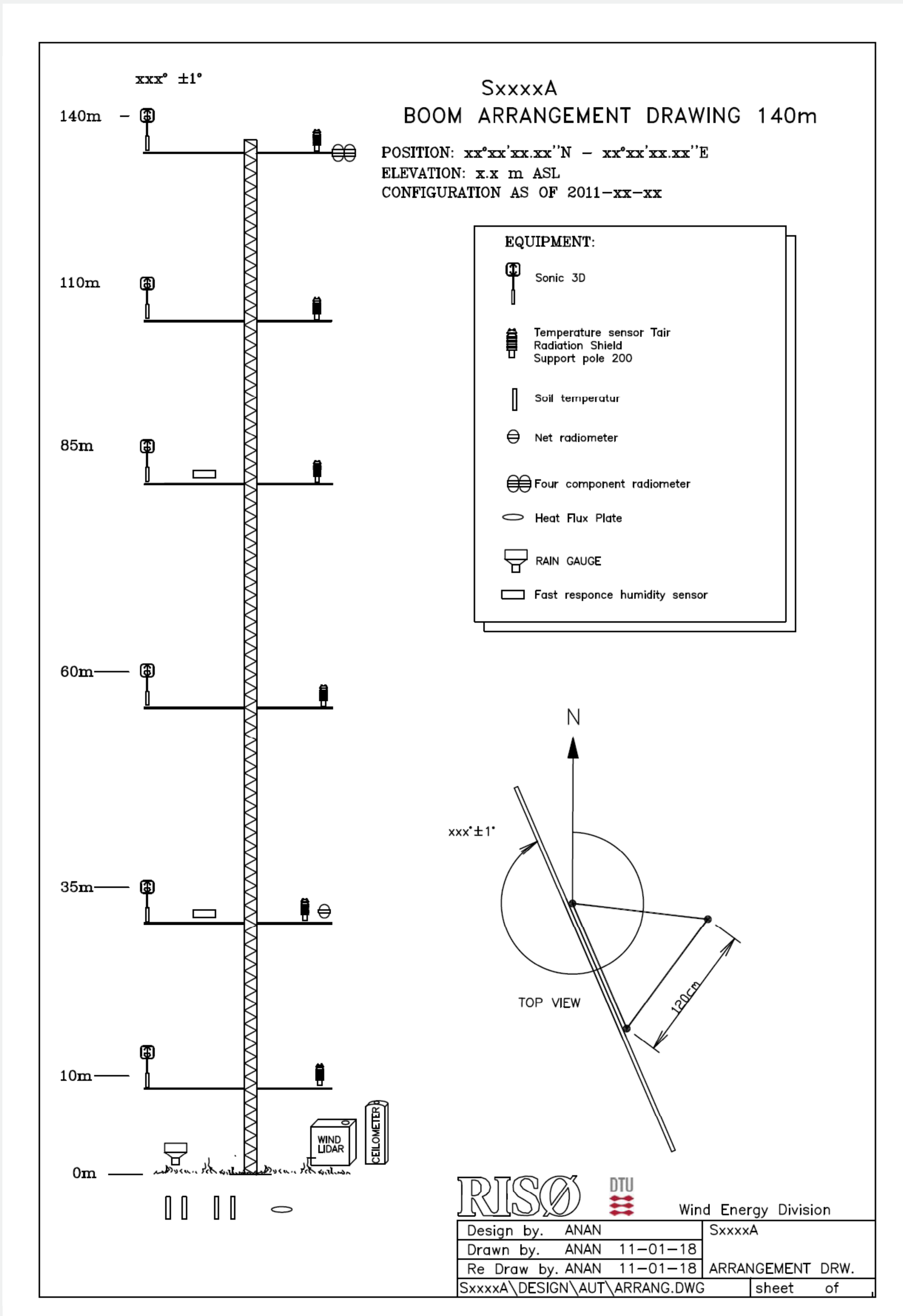


Figure 4: Sketch of mast setup

… AND MORE MEASUREMENTS!

Apart from the surface energy balance, other important measurements include soil temperature and moisture. Whereas the measured long-wave radiation from the surface gives a good estimate of the surface temperature, the soil temperature could be quite different. This is especially true for tall canopies, like forests, where the difference between canopy temperature and soil temperature often give rise to a reversed stratification within the canopy compared to above the canopy, a feature which increases the complexity of the canopy flow. The amount of soil moisture has strong influence on the surface heat fluxes. At low soil moisture levels, the surface will heat up faster, which for example could be important for the strength of sea breezes. This in turn will affect the production of coastal wind parks.

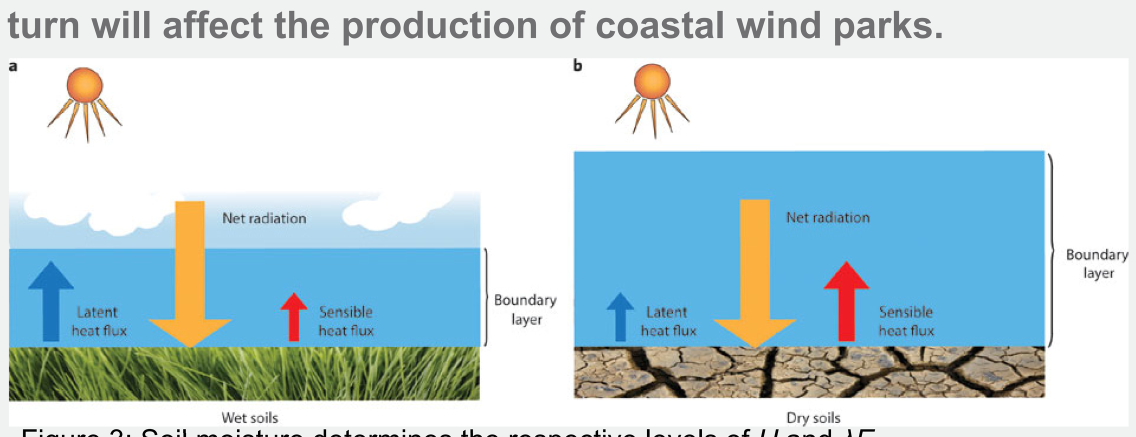


Figure 3: Soil moisture determines the respective levels of H and λE.

NEW POSSIBILITIES FOR MODEL PARAMETERIZATION AND VERIFICATION

By including the measurements of the surface energy balance into an ambitious wind energy experiment, the possibilities of model parameterization and verification are improved. With this extended setup, key parameters like albedo and soil temperature can be directly assessed from data. Further, the extended data set should allow for a better classificationof the measured wind and temperature profiles. This reduces the uncertainty on the surface representation, which should improve the accuracy of wind profile parameterization and verification. For meso-scale models, the energy balance measurements provide the possibblities to better understand model errors. For microscale models, the measurements could provide a good basis for improving the often crude parameterization during non-neutral thermal stratification.

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